

MULTIMODAL ROUTE PLANNING IN MOBILITY AS A SERVICE

Panagiotis Georgakis
Faculty of Science and Engineering
University of Wolverhampton
Wolverhampton, UK
p.georgakis@wlv.ac.uk

Adel Almohammad
Faculty of Science and Engineering
University of Wolverhampton
Wolverhampton, UK
a.almohammad@wlv.ac.uk

Efthimios Bothos
Institute of Computer and
Communication Systems
Athens, Greece
mpthim@mail.ntua.gr

Babis Magoutas
Institute of Computer and
Communication Systems
Athens, Greece
elbabmag@mail.ntua.gr

Kostantina Arnaoutaki
Institute of Computer and
Communication Systems
Athens, Greece
konsarna@mail.ntua.gr

Gregoris Mentzas
Institute of Computer and
Communication Systems
Athens, Greece
gmentzas@mail.ntua.gr

Abstract— Mobility as a Service (MaaS) is a new approach for multimodal transportation in smart cities which refers to the seamless integration of various forms of transport services accessible through one single digital platform. In a MaaS environment there can be a multitude of multi modal options to reach a destination which are derived from combinations of available transport services. Therefore, route planning functionalities in the MaaS era need to be able to generate multimodal routes using constraints related to a user's modal allowances, service provision and limited user preferences (e.g. mode exclusions) and suggest to the traveler the routes that are relevant for specific trips as well as aligned to her/his preferences. In this paper, we describe an architecture for a MaaS multi-modal route planner which integrates i) a dynamic journey planner that aggregates unimodal routes from existing route planners (e.g. Google directions or Here routing), enriches them with innovative mobility services typically found in MaaS schemes, and converts them to multimodal options, while considering aspects of transport network supply and ii) a route recommender that filters and ranks the available routes in an optimal manner, while trying to satisfy travelers' preferences as well as requirements set by the MaaS operator (e.g. environmental friendliness of the routes or promotion of specific modes of transport).

Keywords—Mobility as a Service, route planning, recommender systems, multimodality

I. INTRODUCTION

Urban transportation in the context of a smart city is a complex issue that affects its structure and a main factor for the sustainable development of a city area [1]. Mobility as a Service (MaaS) is a novel mobility concept which has the potential to improve mobility and reduce urban congestion, which are the main challenges faced by smart cities today. It refers to a seamless integration of various forms of transport services accessible through one single digital platform and aims to effect a shift from car ownership to car usership, which supported by efficient public transport services can reduce the number of private vehicles in smart cities. MaaS places users at the core of transport services by offering them tailor made mobility solutions according to their individual needs. To meet a traveler's needs, MaaS facilitates the integration of diverse sets of transport options, spanning from public transport, rail, ride-, car- or bike-sharing, taxi or car rental/lease. For the traveler, MaaS offers added value by hiding the complexity of the underlying multimodal transport network through the use of a single application that provides unified access to multimodal mobility, with integrated and

personalized route planning, booking of services and payment [2]. The concept of MaaS is integral to the advancements of smart cities, as it requires integration of different technologies and data sources to offer the above stated services to travellers. From a technological perspective, the operation of MaaS requires integration with smart city platforms as to realise a seamless integration of multimodal services. Smart city systems such as traffic management, smart parking, public transport monitoring, trip planning and others are necessary for the operation of a holistic MaaS application that can fully meet the needs of modern travellers.

From an organizational viewpoint, MaaS is offered by a new type of mobility operators the "MaaS Operators" which are intermediary companies that make agreements with public and private transport service providers and offer subscriptions to bundles of transport services, the "MaaS plans" or mobility products [3]. Access to the transport services is achieved through mobility apps and related back-end platforms that are provided by the MaaS operators and integrate all the available transport services while providing a single point for their use.

In a MaaS environment there can be a multitude of multi modal options to reach a destination which are derived from combinations of available transport services. For example, a traveler whose MaaS plan combines and includes services such as public transport, taxi, car sharing, bike sharing, car rental and/or other related services can use any combination of these services to reach her/his destination.

Therefore, route planning functionalities in the MaaS era need to be able to generate multi-modal routes using constraints related to a user's modal allowances, service provision and limited user preferences (e.g. mode exclusions) and suggest to the traveler the routes that are relevant for specific trips as well as aligned to her/his preferences.

In this paper, we describe an architecture for a multi-modal route planner which is being developed in the context of MaaS4EU, an EU-funded research project, that aims to provide insights on how MaaS can be effectively deployed in different settings. The proposed architecture considers two main components: i) a dynamic journey planner that aggregates unimodal routes from existing route planners (e.g. Google directions or Here routing), enriches them with innovative mobility services typically found in MaaS schemes, and converts them to multimodal options, while considering aspects of transport network supply and ii) a route recommender that filters and ranks the available routes in an

optimal manner, while trying to satisfy travelers' preferences as well as requirements set by the MaaS operator (e.g. environmental friendliness of the routes or promotion of specific modes of transport).

The remainder of this paper is organized as follows. In Section 2 we discuss related work and in Section 3 we present the proposed architecture and describe the details of its elements. In Section 4 we conclude with a summary of the current status regarding the implementation of the proposed architecture as well as our plans for evaluation.

II. RELATED WORK

Nowadays, travelers use different types of route planning platforms to travel from an origin to a destination effortlessly. Generally, route planners inform users about routes to follow, distances between start and end points, arriving time, prices, points of interest, location, number of transfers, and connections with other means of transport ([4], [5]).

Multimodal routing is the process that uses various transportation modes (public transportation, car driving, cycling, walking, etc.) to find an optimal route between the source and the destination of a trip. Therefore, the term "multimodal routing" refers to the derivation of routes in a given time interval, and with the use of different modes of transport. The goal of multimodal route planning is to provide the user with optimal, feasible and personalized routes (involving public and private Modes Of Transport, hereafter referred to as MOTs) between origin and destination [6]. In contrast, the term unimodal routing is defined as routing from origin to destination using a single mode of transport without mode changes [7].

Traditional route planners such as Google Maps and Bing as well as innovative planning and navigation applications such as Citymapper and Waze have some limitations since they primarily offer trip options composed of one mode of transport (private vehicles, public transport, walking or cycling), or limited combination of modes (for example, bike or walking for access to a public transport service, train/tram with taxi services). Additionally, most of these journey planners do not consider other mobility services such as on-demand and car sharing ([8]; [9]).

However, recent work has focused on the problem of multimodal routes generation. In order to provide a free combination of multiple travel modes and considering all feasible routes, an improved genetic algorithm (GA) approach is proposed by [6] to solve the multi-modal route planning problem. GA can handle multi-criteria optimal problems (e.g. time, transfer and cost) and provide a set of solutions simultaneously during one process. The multimodal routing graph considers the union of all subgraphs representing all different MOTs, and each mode is represented as a separate layer, while transfer links or nodes connect each of them. In this graph, an associated weight for each edge is represented as a p -dimensional vector of criteria, while an edge is represented by a single criterion (e.g. distance or time) in unimodal routing. In this approach, routes are represented by using variable length chromosomes and subchromosomes (parts and each part represents a MOT). Basically, this approach predefines crossover and mutation operators in single mode, predefines hypercrossover and hypermutation operators (to achieve new individuals from different MOTs), and adopts a p -dimensional vector with the concept of dominate as a fitness function (to represent multiple criteria)

for selecting the optimal solutions. As a result, a free combination of different MOTs (walking, bus, taxi) has been implemented on multimodal network with concerning various individual needs (time, fare, and transfer) and provided a various mode combination.

Hrncir and Jakob [10] suggested the use of generalised time-dependent graphs (GTD) to solve the multimodal journey planning problem (a journey plan involves PT, individual, and on-demand transport modes). Briefly, the proposed approach depends on converting this problem into a standard graph search problem to be solved by general shortest path algorithms. The GTD graph, which supports multimodal journeys, connects the network graph (pavements, cycleways, and roads) with the time-dependent graph (scheduled PT services like bus, tram, underground) in a unified graph by using a graph connector. Additionally, a journey plan template notion has been used to provide a way of parameterizing the journey planner and obtain user-friendly plans (e.g. environmentally friendly, fastest, restricted MOTs, or cheapest). Basically, it uses a contextual GTD graph, which stores the node context (i.e. the time of arrival and the modes of transport sequence used) in the GTD graph. A general shortest path algorithm (e.g., A* or Dijkstra) is used to find a path in the contextual GTD graph from the origin contextual node to the destination contextual node. Finally, this found path is transformed into a journey plan using a function (to append a sequence of edges with same modes to a leg and set the corresponding departure and arrival times).

Prandtstetter, et al. [11] proposed multi-modal routing methods to compute intermodal routes including car, bicycle, public transportation, car-sharing, bike-sharing, and walking, such that all these modes of transport (MOTs) can be used within a single route. One possible design to perform a multi-modal trip planner on a directed graph is by considering each arc as a physical infrastructure (e.g. a road) and access restrictions (e.g. only walking is allowed over this edge). Another possible design can be achieved by introducing a layered network where each layer of the network corresponds to one possible MOT (e.g. car or bicycle). However, the layered network approach is used to compute multi-modal routes. All MOTs layers are linked to each other and a walking graph is considered as a reference to all other nodes to be connected to it. Additionally, the concept of modelling walking times/distances (weights have been given) for transfers between different PT stops/stations and between different MOTs (e.g. car to walking). As soon as the complete graph is obtained, Dijkstra's algorithm is executed and is providing the multi-modal route (with the minimum weight) from source node to the target node.

For further details about the multimodal route planning problem, Bast et al. [12] provides a general survey in route planning algorithms for transportation networks. Additionally, many multimodal route planning algorithms were grouped in three distinct approaches; Combining Costs approach, Label-Constrained Shortest Paths, and Access-Node Routing.

Current implementations of multimodal journey planners are primarily based on the generation of multi-layered graphs and the application of traditional shortest path algorithms for the generation of routes. Although this approach performs well, when a limited number of semi-dynamic modes needs to be considered, it poses limitations for journey planning applications in true MaaS provisions, including:

- Integration of on-demand services (ride hailing, taxis, etc.) is problematic during the on-the-fly generation of graphs due to the substantial number of possible pick-up locations.
- The multidimensional constraints linked to MaaS (i.e., access allowance for services based on duration, time of

journeys to include legs serviced with different means of transport (e.g. bike, shared car and public transportation) as if they are provided by a single operator.

In order to cater for the multimodal requirements of a MaaS ecosystem, we have designed the MaaS route planning architecture as shown in Fig. 1. The architecture integrates a

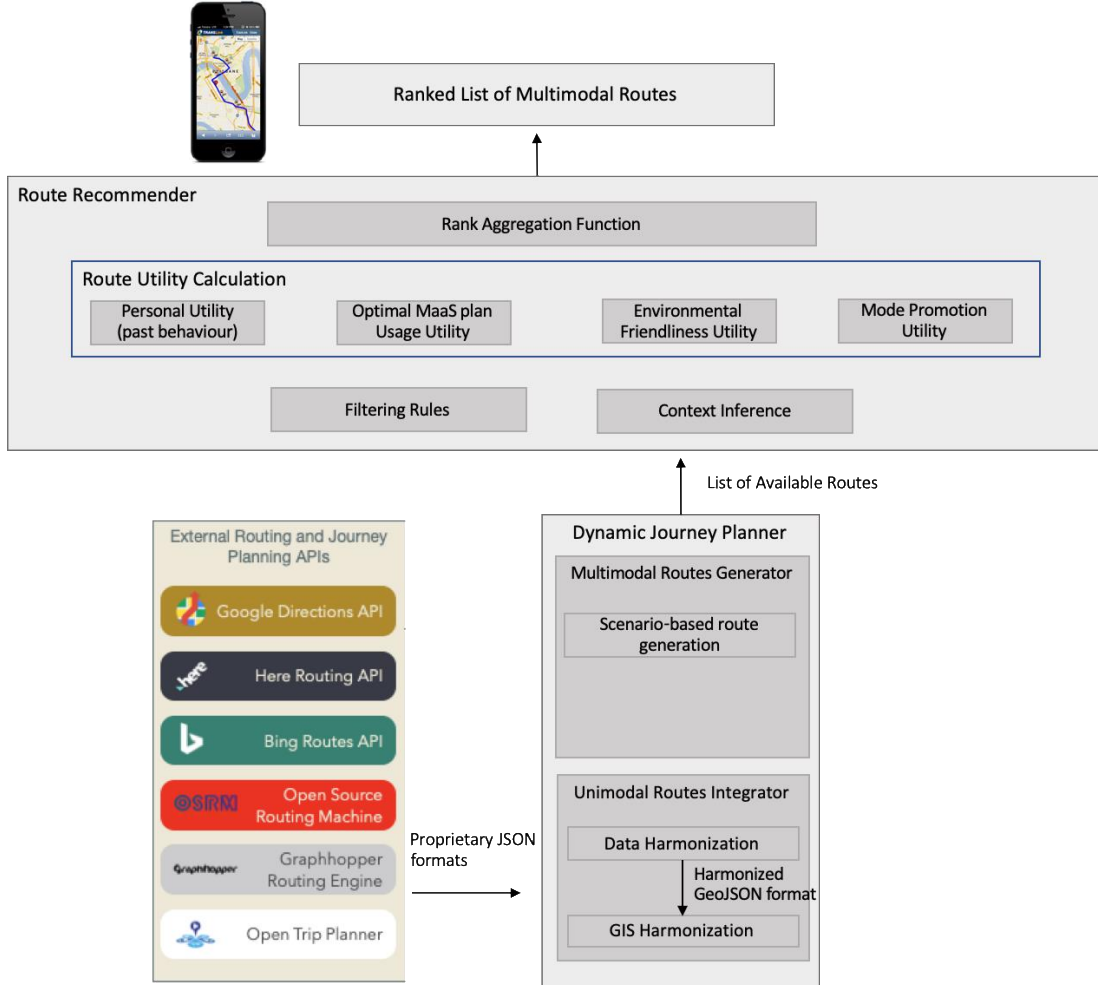


Fig. 1: Overview of the proposed Architecture.

day, distance, number of trips, etc.) cannot be easily transcribed to weights that may affect the output of conventional route generators.

- Context awareness attributes related to personal preferences, environmental conditions, modal or service promotion and others cannot be used seamlessly as part of the path generation of the existing solutions.

The following sections of the paper describe our approach which overcomes the above stated limitations.

III. APPROACH

Generally, mobility service providers offer journeys with different modes of transport. Since mobility resources are owned and administrated by multiple mobility operators, travel planning for each section of a journey (“leg” or “hop”) requires interaction with a specific operator. The main goal of Mobility as a Service (MaaS) operator is collecting and aggregating services (parts of routes) from multiple mobility service providers in order to provide transparent multimodal journeys to its users. Therefore, MaaS travelers can plan their

dynamic route planning component that offers true multimodal journey planning by combining the unimodal results of existing routing engines and enriching them with segments that can be realized by innovative mobility services. Moreover, it integrates a route recommendation service that considers a list of alternative routes for travelling from A to B provided by the dynamic journey planner component, filters out irrelevant routes, calculates a utility for the remaining routes, and properly structures them on the basis of their utilities, in the sense that the route with the highest utility is ranked first.

A. Dynamic Journey Planner

The Dynamic journey planner involves two main modules the unimodal routes integrator and the multimodal routes generator. The first module is responsible for collecting various unimodal routes generated by external routing APIs, either open source or closed source. Routes from routing engines such as Google Directions, Here Routing, Bing Routes, Open Source Routing Machine (OSRM), Graphhopper and Open Trip Planner (OTP) are generated by the said module. Each API is utilized to generate unimodal

routes according to its functionality and performance. For example, OSRM, as an open source solution, can run on local machines and due to its fast computation performance is being used to generate cycling and walking routes, while commercial APIs such as Google, Here and Bing, incorporate real-time traffic information as part of their functionality and therefore are used to generate car and public transport routes. The available unimodal routes are then harmonized and used as input for the second module of the dynamic journey planner which is the multimodal routes generator where different segments of unimodal routes are combined in order to infer corresponding multimodal routes.

1) GIS Data Harmonization

In order to analyse and process the route-related data, collected from various routing APIs, their transformation to a harmonized structure is needed. Our approach is to rely on the extendible GeoJSON format. GeoJSON is a data format for encoding geographic data structures using JavaScript Object

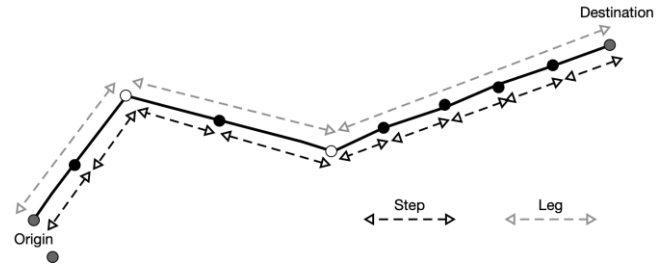


Fig. 3: Example of harmonised route's components (legs & steps).

Apart from the harmonisation of data due to the variety of proprietary formats supported by the different routing APIs, geometry harmonisation was also considered. This is due to the differences in the maps used by each API. For example, a single intersection of the road network could be represented by two different coordinate pairs (lon, lat) in the responses

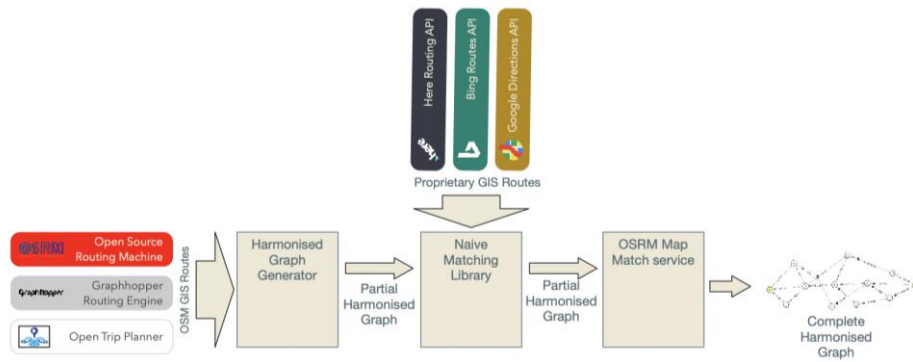


Fig. 2: GIS Harmonisation Process

Notation (JSON). Using GeoJSON, several types of JSON objects can be defined and combined to represent data about geographical structures and properties of these structures (non-spatial). GeoJSON supports many geometry types including points (addresses and locations), line strings (streets and highways), and polygons (countries and provinces) [13]. Fig. 2 shows an example for GeoJSON data format. It represents a LineString geometry type as the four coordinates make a line or a road segment.

The result of the GeoJSON harmonization is a set of routes with the same structure. The LineString geometry type is the one mainly used as the calculated routes are constructed from road segments or lines. Moreover, only important properties are considered in this data harmonisation process such as transport mode, distance, travel time, and geometry while the other properties of the original route-related data are omitted. Each harmonized route includes at least one leg, and each leg includes at least one step (see the example in Fig. 3). In the case of routes that include public transport legs, then the steps are replaced by the stops of the particular service.

returned by the external journey planning systems. Since OpenStreetMaps is an open source solution, and three of the APIs already supported it, it was chosen to be used as the common GIS reference. The developed GIS harmonisation process can be seen in Fig. 3.

The following techniques have been used in each step:

- a) The partial harmonised graph generation step uses the routes returned by the three OSM compatible services and generates a graph with vertices being OSM nodes and edges being OSM ways (or their derivatives due to transformations that take place for making raw OSM maps routable).
- b) A naïve matching library has been developed for comparing non-compatible OSM routes to elements of the partial harmonised graph developed during step a. For the naïve matching to be complete all nodes of a non-compatible OSM route must be matched with nodes, or edges included in the partial harmonised graph. The following matching options are defined (Fig. 4):
 - a. Node-to-Node: When $d(u, v) < T$, where:
 - i. $d(u, v)$ is the Euclidean distance between points u and v .
 - ii. T is a threshold value set to 5 meters.

- b. Node-to-Edge: When $d \perp (e, x) < T$, where:
- $d \perp (e, x)$ is the length of a perpendicular line from point x to edge e .
 - T is a threshold value set to 5 meters.

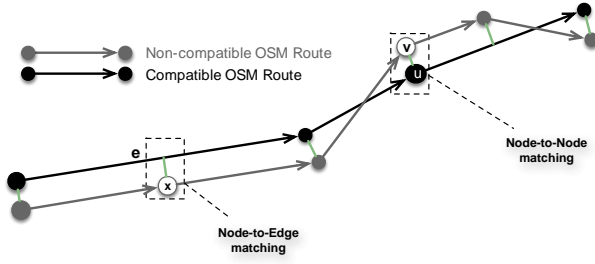


Fig. 5: Matching options for naive GIS harmonisation library

- c) All routes that cannot be matched using the naive matching library are processed through the OSRM map match service, which implements a hidden Markov map matching algorithm [15]. The resultant sequences of nodes and edges are added to the partial harmonised graph to complete the GIS harmonisation process.

2) Multimodal Routes Generator

To allow the generation of multimodal routes that incorporate non-conventional services and modes which can be part of a MaaS Plan (e.g. car and bicycle sharing, on demand transport, etc.) we have specified a number of scenarios. Each scenario is responsible for substituting segments of unimodal routes (Walking: W, Bicycle: B, Private car: C, Public Transport: PT) with paths that can be traversed with additional services (Bike Share: BS, Taxi: TX, Car Club: CC).

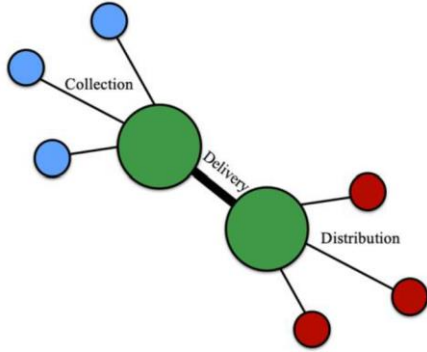


Fig. 6: Multimodal trip composition.

Typical multimodal journeys are composed of three distinct stages namely collection, delivery and distribution (Fig. 6), with the delivery stage constituting the longest segment of the trip.

Our developed scenarios are based on the following assumptions:

- The collection stage allows travelling from the origin to an interchange for access to the main mode of transport to be used in the delivery stage. We consider that a private car, on-demand services (taxi) or bicycle (including bike sharing) can be used at this stage.

- The delivery stage (typically a long-distance segment) requires the use of either a public transport (including private mass transit) service, or car sharing (car club).
- Finally, the distribution stage can be realized by flexible modes accessible away from home/work such as on-demand services and bike sharing.

Based on the above assumptions the following exemplar scenarios have been developed. The information required for the generation of these scenarios was acquired through APIs that were made available by the different service providers, or publicly available data sources.

Table 1: Information Sources for Scenarios

Scenario	Information	Source
1, 2	Parking Information	Open Street Map (static), Smart Parking Systems (dynamic).
1, 3, 4	Estimated time of arrival for taxi at a particular location	API provided by the taxi operator.
2, 3	Location of bike sharing station	API provided by the bike sharing operator.
4	Location of car sharing vehicles	API provided by the car sharing operator.

Scenario 1: Private Car → Park and Ride (P&R) → Public Transport → Taxi

In this scenario a traveller uses Park & Ride to access a public transport hub and completes the journey using a taxi from the public transport's drop off points to the destination address. Such a scenario is applicable when the trip destination is not a regular place of visit and the public transport unimodal route is composed of 'slow' modes (i.e. walking and bus) for collection and distribution and a 'fast' service (i.e. rail) for the delivery stage. The key steps for generating this type of multimodal route are:

- Define 'boarding', 'change over' and 'alight' points of public transport routes.
- Derive car routes from the 'origin' point to 'boarding' and 'change over' points.
- Request taxi service availability from the 'alight' point to the 'destination' point.
- Construct multimodal routes by integrating the three journey stages together.

A process diagram for the implementation of this functionality as part of the dynamic journey planner can be seen in Fig. 4.

Similarly, to the above, numerous scenarios that can facilitate the Collection → Delivery → Distribution paradigm can be defined. Examples, of such scenarios that cover typical services found in MaaS schemes are as follows:

Scenario 2: Private Car → Park and Ride (P&R) → Public Transport → Bike Sharing

This is a variation of scenario 1, where the distribution stage is short enough to be travelled by a bicycle. Since, the

bicycle segment is the last of the journey a bike sharing service is required. The process diagram for the realisation of this scenario can be seen in Fig. 7, while the main functionality from the journey planner's perspective is:

- Define 'boarding', 'change over' and 'alight' points of public transport routes.
- Derive car routes from the 'origin' point to 'boarding' and 'change over' points.
- Determine bike-sharing pick-up locations close to the 'alight' point.
- Generate walking route from the 'alight' point to the bike-sharing pick-up point.
- Generate cycling route from the bicycle pick-up point to the 'destination' point.
- Construct multimodal routes by integrating the three journey stages together.

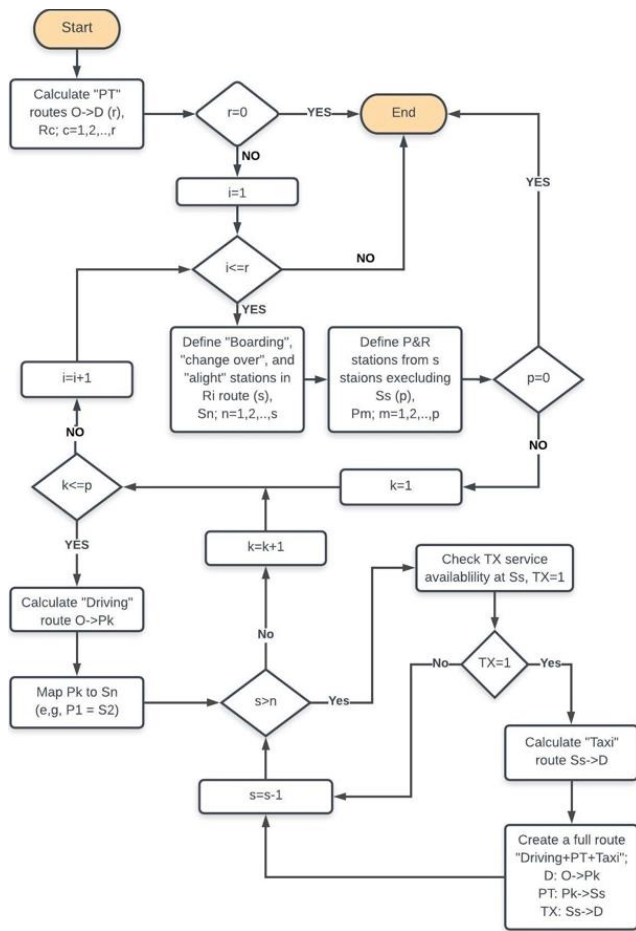


Fig. 7: Process diagram for scenario 1: Taxi → Public Transport → Taxi

In this scenario, a traveller uses a taxi service in both collection and distribution stages. This is a variation of scenario 1, but for users who do not have access to a private car. Therefore, a taxi is required to access a public transport hub and to complete the journey from the public transport's drop off point to the destination. A traveller can follow such a scenario when the origin and destination points are not close to any public transport stop/station. In such case, the public transport represents a suitable mode to be used at the delivery stage (i.e. fast rail service) when the collection and distribution stages cannot be facilitated by other mobility services (e.g.

private car, bike or walking). The key steps for generating this type of multimodal route are:

- Define 'boarding', 'change over' and 'alight' points of public transport routes.
- Request taxi service availability from the 'origin' point to the 'boarding' and 'change over' points.
- Request taxi service availability from the 'alight' point to the 'destination' point.
- Construct multimodal routes by integrating the three journey stages together.

Scenario 3: Taxi → Public Transport → Bike Sharing

In this scenario, a traveller uses a taxi service in the collection stage to access a public transport interchange point, and a bicycle is used to complete the journey to the destination. Such a scenario is applicable when access from the origin to a public transport service is limited to taxi services (other mobility services are unlikely possible). The key steps for generating this type of multimodal route are:

- Define 'boarding', 'change over' and 'alight' points of public transport routes.
- Request taxi service availability from the 'origin' point to the 'boarding' and 'change over' points.
- Determine bike-sharing pick-up locations close to the 'alight' point.
- Generate walking route from the 'alight' point to the bike-sharing pick-up point.
- Generate cycling route from the bicycle pick-up point to the 'destination' point.
- Construct multimodal routes by integrating the three journey stages together.

Scenario 4: Taxi → Car Sharing → Public Transport

In this scenario, a traveller uses a taxi service in the collection stage to access a car sharing service and subsequently public transport is used to complete the journey to the destination. Such a scenario is applicable when the origin and the destination of a journey is outside the operational region of a car sharing service and alternative modes are used for the collection and distribution stages of the trip. The key steps for generating this type of multimodal route are:

- Determine car sharing vehicle locations close to the origin.
- Request taxi service availability from the 'origin' point to the car sharing vehicle collection point.
- Determine the public transport 'boarding' stop/station closest to the destination and within the operating region of the car sharing service.
- Generate driving route from the car sharing collection point to the public transport 'boarding' location.
- Construct multimodal routes by integrating the three journey stages together.

B. Route Recommender

The aim of the Route Recommender is to support users in the everyday use of MaaS and more specifically their

transportation decisions, by providing a personalised list of multimodal and unimodal routes. Given a list of alternatives route choices for travelling from A to B generated by the dynamic journey planner, the route recommendation service properly structures the available choices through choice architecture design elements. The choice architecture approach provides proper default options and, filters and ranks the route options according to user goals and preferences. Moreover, the service considers optimal use of the MaaS plan the user has subscribed to, as well as the impact on the environment and related long-term effects of potential user choices. Specific goals and preferences of the MaaS operator, such as a preference of a particular mode of transport over another are also considered in the process of structuring the available user choices. To this end and when such a need arises, travelers are nudged towards selecting specific options such as sustainable ones and in the long term change their behaviour and select routes that lead e.g. to reduced emissions in that case. The service offers an intelligent decision system, which is tailored for route choice applications and can assist urban travelers and commuters to select transportation options that are comfortable, yet satisfying the MaaS operator goals and leading to an optimal use of the MaaS plans.

1) Filtering Rules

The aim of the filtering rules is to remove route options that do not make sense for the current user. A set of checks has been implemented and each available route undergoes the process of checking for specific route characteristics. In case the system identifies characteristics that are not relevant for the user, the route is removed from the available set.

- For users without a driving license, routes with mode of transport car are excluded.
- For users who don't know how to bike, routes with mode of transport bicycle are excluded.
- Routes with long bicycle distances (as defined by the user) are excluded.
- Routes with long walking distances (as defined by the user) are excluded.

2) Context Inference

The route recommendation service leverages context to affect travellers' decisions towards selecting routes that match user preferences, contribute to the optimal use of the MaaS plan the user has subscribed to, while satisfying the MaaS operator's goals. In order to be able to acquire a broad and inclusive understanding of the concept of context in travel choices, we performed an analysis of related studies [14, 16]. Our aim was to collect situational and contextual factors which are relevant for travel behaviour and travel decisions.

The aforementioned analysis resulted in a broad and inclusive understanding of the concept of context in travel choices, based on which we have selected a number of situational and contextual factors which are relevant for a MaaS route recommendation service. The variables are binary, which means that they are activated when the conditions that define them are present and depend on the characteristics of the alternative routes for the current trip, the user's profile and recorded behavior, and the state of the weather. More specifically there are four groups of variables as follows.

1. Based on the users' past behaviour, which are calculated using as input past choices the user has made in the period following the subscription to a MaaS plan and the inferred behaviour as it is logged through the usage of the subscribed MaaS plan. These context variables include:

- Increased car sharing usage trend
- Increased bike sharing usage trend
- Increased taxi usage trend
- Increased ride sharing usage trend

These context variables can be activated with the use of sliding-window based functions that analyse the usage of the different modes (car sharing, bike sharing, taxi and ride sharing) in terms of quota that has been used since the start of the window (i.e. the time a user subscribes or renews his/her subscription to a MaaS plan that includes the corresponding modes) and compares it to the uniform consumption of the MaaS plan's available quota for the specific modes. In case the difference exceeds a configurable threshold and the remaining time until the end of the subscription period is below another configurable threshold, the context variable is set to True.

3. Based on trip characteristics, which can be calculated using as input the available routes. These context variables are activated on a per route basis and include the following:

- Walking Distance
- Bike Distance

It means that the total walking or bike distance needed to reach the destination is acceptable by the user. In this case users should be able to configure in their profile their preference with respect to the maximum distance they would be willing to walk or cycle within a multimodal route. In cases when the route walking or bike distance is lower than the threshold set by the user, this context variable is set to True.

- Electric bus: This context variable is activated when a bus route is mainly performed with an electric bus.

4. Based on combination of users' past behaviour and trip characteristics, which can be calculated using as input both past choices the user has made in the period following the subscription to a MaaS plan, and well as the available routes. The following context variable is activated on a per route basis:

- Unfamiliar mode or route: Activated when the user is unfamiliar with a route mode or the route itself. User stated preferences, as well as lack of previous user interactions with the MaaS app involving the particular mode or route, are used as measures of route mode and route unfamiliarity, respectively.

5. Based on environmental information. In this case, we make use of information about the environment in which the route recommendation takes place. We define the following variable:

- Nice Weather: It refers to the current status of the weather and is set to True when the temperature level exceeds a certain configurable threshold and the precipitation level is below another configurable threshold.

6. Based on a combination of environmental information and trip characteristics. We make use of information about both the business environment in which the route recommendation takes place and the available routes. The following context variable is activated on a per route basis:

- Promoted Mode Route: Activated when the main mode of a route alternative is one that the MaaS operator wants to promote in the current time period. The variable is activated when the total distance that needs to be covered in a route alternative with the mode to be promoted exceeds a configurable threshold.

- Promoted Mobility Service Provider Route: This context variable is activated when the main mode of a route alternative is one provided by a Mobility Service Provider (MSP) the MaaS operator wants to promote in the current time period.

3) Route Utility Calculation and Ranking

The aim of the Route Utility calculation function is to process the available routes and estimate a personalized utility per route for the specific user in the current context. The utility is used for ranking the routes and presenting them such that routes which adhere to user preferences as well as the current context and contribute to the optimal use of the MaaS plan the user has subscribed to, are ranked higher. The goal is to highlight the routes that lead to the optimal use of the MaaS plan, while respecting user preferences, considering the current context, and increasing their chances of being selected. Eventually, the utility calculation function supports user decisions towards a personalised and context-aware MaaS experience.

The Route Utility calculation function comprises of several sub-functions. In more details the sub-functions provide different views of how the routes should be ordered and presented to the users, which are eventually consolidated in a single ranked list of routes that are communicated to users through a MaaS mobile application. The sub-functions fall under two main views of how the routes should be ordered:

- i) The personal user view that considers user preferences and their potential variations in different contexts based on past user interactions with the MaaS4EU application.

- ii) The system and context view, which refers to a computational process that leads to the identification of the current context of the user and a user model that infers preferences through the analysis of past behaviour including user trips and selections of routes in a MaaS app. The system view is configured such that it promotes optimal usage of the MaaS plan, a goal reflected in the optimal MaaS plan usage sub-function. Additional goals of the system view that can be optionally activated in the route recommendation service configuration, include the provision of environmentally friendly routes (reflected in the environmental friendliness sub-function), the provision of routes that consider user happiness and stress levels (reflected in the user stress & happiness sub-function), as well as the provision of routes promoting specific transport modes or mobility service providers the MaaS operator wants to promote.

The different route lists are consolidated using the Borda count algorithm and the sum of ranks generated by individual ranking functions to obtain the fused rank [17]. Borda Count ranks the documents based on their positions in the basic rankings. If any document has a high ranking in basic rankings

it is counted as a high ranking in the final ranking list. The scores of ranking routes in the final ranking list can be calculated as:

$$S_R = \begin{bmatrix} S_{i1} \\ \vdots \\ S_{ij} \\ \vdots \\ S_{kn} \end{bmatrix} \quad F(S_i) = \sum_{i=1}^k S_i$$

Where S_R is a matrix that contains k ranked lists of n alternatives routes in its columns (one for each defined utility function) and $F(S_i)$ is the final score of route i based on its positions in the k ranked lists of routes.

IV. CONSLUSIONS

In this paper, we presented the architecture of a route planner for the Mobility as a Service (MaaS) mobility paradigm. MaaS aims to provide integrated and seamless access to transport services through one single digital platform in smart city contexts. In a MaaS environment there can be a multitude of MaaS plans, that include combinations of transport services, in order to meet the specific needs of different types of travelers. The aim of our journey planner is to provide multimodal route options and support travelers' to identify and select routes that lead to the optimal use of their MaaS plan, while respecting their preferences. To the best of our knowledge the proposed route planner consists the first attempt for introducing true multimodality in MaaS ecosystems.

As part of our next steps, we are in the process of implementing and evaluating our proposed architecture in real life conditions where travelers from the cities of Manchester, Budapest and Luxemburg will be using a MaaS app integrating our journey planner in October 2019. Our aim is to test our approach and measure the effectiveness and benefits of MaaS personalized route suggestions to travelers.

ACKNOWLEDGMENT

Research reported in this paper has received funding by the H2020 EC project MaaS4EU (GA no. 723176).

REFERENCES

- [1] Jönson G., & Tengström E. (2006). Urban Transport Development: A Complex Issue. Springer Science & Business Media.
- [2] Durand, A., Harms, L., Hoogendoorn-Lanser, S., & Zijlstra, T. (2018). Mobility-as-a-Service and changes in travel preferences and travel behaviour: a literature review. KiM Netherlands Institute for Transport Policy Analysis.
- [3] Kamargianni, M., & Matyas, M. (2017). The business ecosystem of mobility-as-a-service. In transportation research board (Vol. 96). Transportation Research Board.
- [4] Ștefănescu, P., Mocan, M., Ștefănescu, W., & Neculai, P. V. (2014). Trip Planners Used in Public Transportation. Case Study on the City of Timișoara. Procedia-Social and Behavioral Sciences, 124, 142-148.
- [5] Rahaman, M. S., Mei, Y., Hamilton, M., & Salim, F. D. (2017). CAPRA: A contour-based accessible path routing algorithm. Information Sciences, 385, 157-173.
- [6] Yu, H., & Lu, F. (2012). A multi-modal route planning approach with an improved genetic algorithm. Advances in Geo-Spatial Information Science, 193.
- [7] Liu, L. (2011). Data model and algorithms for multimodal route planning with transportation networks (Doctoral dissertation, Technische Universität München).
- [8] Clauss, T., & Döppe, S. (2016). Why do urban travelers select multimodal travel options: A repertory grid analysis. Transportation Research Part A: Policy and Practice, 93, 93-116.

- [9] Kramers, A., Höjer, M., Lövehagen, N., & Wangel, J. (2014). Smart sustainable cities–Exploring ICT solutions for reduced energy use in cities. *Environmental modelling & software*, 56, 52-62.
- [10] Hrnčir, J., & Jakob, M. (2013). (2013). Generalised time-dependent Graphs for fully multimodal journey planning. Paper presented at the Proceedings of the 16th International IEEE Annual Conference on Intelligent Transportation Systems (ITSC 2013), The Netherlands.
- [11] Prandtstetter, M., Straub, M., & Puchinger, J. (2013). On the way to a multi-modal energy-efficient route. Paper presented at the 39th Annual Conference of the IEEE Industrial Electronics Society, IECON 2013, Vienna.
- [12] Bast, H., Delling, D., Goldberg, A., Müller-Hannemann, M., Pajor, T., Sanders, P., Wagner, D., Werneck, R. F. (2016). *Route planning in transportation networks*. Algorithm Engineering, Springer, 19-80.
- [13] Gillies, S., Butler, H., Daly, M., Doyle, A., & Schaub, T. (2016). The GeoJSON Format. *coordinates*, 102, 0-5.
- [14] Lamsfus, C., Wang, D., Alzua-Sorzabal, A., & Xiang, Z. (2015). Going mobile defining context for on-the-go travelers. *Journal of Travel Research*, 54(6), 691-701.
- [15] Newson, P., Krumm, J. (2009), Hidden Markov Map Matching Through Noise and Sparseness, 17th ACM SIGSPATIAL International Conference on Advances in Geographic Information Systems (ACM SIGSPATIAL GIS 2009), November 4-6, Seattle, WA | November 2009
- [16] Gretzel, U., Hwang, Y. H., & Fesenmaier, D. R. (2012). Informing destination recommender systems design and evaluation through quantitative research. *International Journal of Culture, Tourism and Hospitality Research*, 6(4), 297-315.
- [17] Benediktsson J.A. and I. Kanellopoulos. Classification of multisource and hyperspectral data based on decision. *IEEE Transactions On Geoscience And Remote Sensing*, 1999.